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Effects of a standing and three dynamic workstations on computer task performance and cognitive function tests

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ABSTRACT

Sedentary work entails health risks. Dynamic (or active) workstations, at which computer tasks can be combined with physical activity, may reduce the risks of sedentary behaviour. The aim of this study was to evaluate short term task performance while working on three dynamic workstations: a treadmill, an elliptical trainer, a bicycle ergometer and a conventional standing workstation. A standard sitting workstation served as control condition. Fifteen Dutch adults performed five standardised but common office tasks in an office-like laboratory setting. Both objective and perceived work performance were measured. With the exception of high precision mouse tasks, short term work performance was not affected by working on a dynamic or a standing workstation. The participant's perception of decreased performance might complicate the acceptance of dynamic workstations, although most participants indicate that they would use a dynamic workstation if available at the workplace.

1. Introduction

The adverse health effects of insufficient physical activity have been known for many years. Physical inactivity is associated with, among others, cardiovascular disorders, type II diabetes, depression, obesity and some forms of cancer (Garber et al., 2011). The World Health Organisation (WHO, 2013) estimates that each year, 3.2 million people worldwide die a premature death because of an inactive lifestyle. Persons who meet the current guidelines on physical activity and health are still exposed to increased health risks, if they are engaged in sedentary work (van der Ploeg et al., 2012), i.e. work that is characterised by long periods of uninterrupted sitting. So far, premature death in general, type II diabetes and obesity have been associated with sedentary work, although the evidence for mortality is stronger than that for morbidity (van Uffelen et al., 2010). A dose–response relationship between health problems and sitting time was reported: each 2 h per day increase in sitting time at work was associated with a 5% increase in risk of obesity and a 7% increase in risk of diabetes (Hu et al., 2003). Physically active persons who reported to be "sitting almost all of the time" had a 1.4 times higher chance to be dead 12 years after the start of the study than their counterparts who reported to be "sitting almost none of the time" (Katzmarzyk et al., 2009).

The number of persons exposed to the sedentary work related health risks is difficult to estimate, since a commonly accepted definition of sedentary work is absent. In 2012, the Sedentary Behaviour Research Network proposed a definition of sedentary behaviour as "any waking behaviour characterized by an energy expenditure ≤1.5 METs while in a sitting or reclining posture". In The Netherlands, about 50% of the adult working population reports sitting 4 or more hours per day at work (report period 2000–2004; Bakhuys Roozeboom et al., 2007). Based on the self-reported hours of computer time at work in Koppes et al. (2012), sedentary work is estimated to be most prevalent in the Dutch sectors ICT (6.9 h computer time per day), financial institutions (6.7 h/d), public administration (5.4 h/d) and business services (4.9 h/d). For the USA, Church et al. (2011) stated that in 2008, about 25% of all occupations had a sedentary character (<2.0 METs), whereas this was only 15% in 1960. In the USA, sedentary occupations are, like in the Netherlands, located in the sectors information, financial activities, and professional and business services. Based on

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the studies above, we estimate that between 25% and 50% of all adults in Europe and the USA are exposed to sedentary work related health risks.

Although the link between sitting at work and an increased risk of coronary heart disease was already established in the 1950s by Morris et al. (1953a,b), efforts were mainly aimed at increasing exercise and physical activity in leisure time. In the 1980s, the awareness arose that the workplace could be a platform for physical activity interventions too. Since then, various initiatives have been described, for instance: a fitness program aimed at reducing work related stress (Frew and Bruning, 1988), walking during lunchtime (de Kraker et al., 2005), promoting stair use (Engbers et al., 2007), a workplace-based physical activity program (Naito et al., 2008), active computer breaks in which the employee performs a set of flexibility and/or strength exercises (Samani et al., 2009), and walking or cycling while performing the usual work tasks (Levine and Miller, 2007; Straker et al., 2009). These interventions can be distinguished into physical activity programmes organised in an occupational setting that do not affect the on-going work ('worksite health promotion programmes') and physical activity performed at the workplace during the on-going work ('dynamic workstations'; Commissaris et al. (2011), or 'active workstations'; Ohlinger et al. (2011)). All of these occupational setting interventions primarily focused on increasing physical activity and not on interrupting and decreasing sedentary time (Chau et al., 2010). With regard to sit-stand desks at work, their aim was until recently to prevent musculoskeletal disorders of neck and upper limbs and not to decrease sedentary time (e.g. Robertson et al., 2013).

In recent years, sit-stand workstations have been evaluated with respect to their potential to reduce sedentary time as they provide the most elementary form of 'not sitting' during on-going work. While Alkhajah et al. (2012) report a significant reduction in sedentary time at the workplace following the introduction of a personal sit-stand workstation, Gilson et al. (2012) did not find a significant change in proportion of work time spent in sedentary behaviour after fitting a pod of four height adjustable desks into the centre of an open plan office space. Alkhajah et al. also evaluated acceptability, showing a strong preference of the users (83%) not to return to their old workstation set-up after three months of using the sit-stand workstation. Work performance was evaluated with one question only; when asked if the new workstation improved their productivity, 33% agreed and 22% disagreed (Alkhajah et al. (2012).

The present study concerns a more comprehensive comparison of work performance while working at a standing or at a dynamic workstation with that of working in a traditional seated position. Previous studies on dynamic workstations report positive short term health outcomes, though sometimes at the expense of work performance. Walking while working was found to raise the energy expenditure on average in obese subjects (Thompson et al., 2008; Levine and Miller, 2007), but computer tasks requiring hand or finger use, such as typing and mouse pointing, were performed slower with more errors (John et al., 2009; Straker et al., 2009; Thompson and Levine, 2011; Ohlinger et al., 2011), while the performance of mental tasks was unaffected (John et al., 2009; Cox et al., 2011; Ohlinger et al., 2011). Both stepping and cycling while working increased the energy expenditure compared to sitting, even more than walking did (John et al., 2009; McAlpine et al., 2007). However, more intensive cycling was found to lead to more errors in work performance (Straker et al., 2009). The decline in task performance is suggested to arise from an interference of upper body motions with the arm stability that is required for fine motor tasks (Straker et al., 2009). However, from general studies on the effects of physical exercise on mental and psychological processes, we know that moderate levels of aerobic, steady state exercise bouts up to one hour improve cognitive performance via facilitation of specific stages of information processing (Tomporowski, 2003).

Given the serious health effects of sedentary work and the large number of people exposed to this health risk, innovative health promotion strategies in the workplace are required. Innovative strategies such as dynamic workstations allow sedentary workers to increase their physical activity without interrupting the on-going work. Therefore, the aim of the present study is to evaluate the effects of those workstations on work performance. A joint paper of Botter et al. (submitted for publication) describes the physiological and postural effects, while the paper at hand deals with the short term effects on performance during computer tasks and cognitive function tests. We hypothesise that compared to sitting:

(1)the short term performance of computer tasks requiring fine motor actions of the hands (e.g., mouse pointing and clicking, typing texts) will deteriorate on all dynamic workstations because of the interference of upper body motions with arm stability, and that this decline will be larger at the higher movement intensity;
(2)the short term performance of computer tasks that do not require fine motor actions of the hands (e.g., reading and correcting texts, cognitive function tests) will improve on all dynamic workstations because of the positive effects of moderate levels of aerobic, steady state exercise on mental processes;
(3)the short term perceived task performance will decline on all dynamic workstations because people are not accustomed to perform their work while being physically active at the same time;
(4)the short term objective and perceived performance will not decline nor improve on a standing workstation, since none of the arguments in hypotheses 1–3 is applicable to a standing workstation.

2. Methods

2.1. Participants

Fifteen adults (see Table 1 for details) volunteered to participate in the study. They were recruited by email among connections of TNO employees and a database of test participants. Inclusion criteria were: at least 18 years old, a Body Mass Index (BMI) between 18 and 30, experienced with computer tasks and involved in physical activity/exercise 1–3 times per week, and no musculoskeletal health complaints. Computer experience, physical activity and musculoskeletal health were self-reported. All participants signed an informed consent at the beginning of the test day and received an aforementioned reward of € 100,- afterwards.

Table 1
Participants' information.

Age	29 (SD 12) years	
Gender	8 females–7 males	
Stature	176 (SD 11) cm	
Weight	70 (SD 13) kg	
BMI	22.3 (SD 2.1) kg/m^2	
Fitness (estimated VO_2 max)	44 (SD 8) ml/min/kg	
Exercise intensity	Frequency	Duration
Moderate ($n = 14$)	2.8 (SD 1.2)/week	48 (SD 16) min per exercise
Intensive ($n = 9$)	2.0 (SD 0.5)/week	44 (SD 11) min per exercise
Touch typist	15 participants	

2.2. Experimental design

Using a randomised repeated measures design, the performance of five tasks (four standardised common office tasks and one task comprising four standardised computer-based cognitive function tests, see 2.4 for complete description) was assessed for six different workstation conditions in an office-like laboratory environment under realistic VDU office settings. The five tasks were randomized within each condition and the conditions were in randomized order over the day. Thus, each participant performed all tasks at all workstation conditions.

2.3. Workstations and conditions

The six conditions comprised two static and four dynamic conditions, one workstation for the static conditions and three workstations for the dynamic conditions (Table 2). All workstations were equipped with a standard 17 inch height adjustable computer screen, keyboard and wired mouse (Dell products). The two static conditions were working in a conventional seated (SIT) and a standing (STA) position. The seated position served as the control condition in this study. For the seated condition, a standard office chair (Sedus, Chicago Drehsessel) and a height adjustable desk (EFG) were adjusted by the test leader to fit each participant's body dimensions. For the standing condition, the same height adjustable table was used and adjusted by the test leader to just below the participants' elbow height. The four dynamic conditions were performed on three dynamic workstations. Two commercially available workstations and one custom built workstation were used. The "Treadmill Desk" by Life Span (left image of Fig. 1) is a treadmill, combined with a height adjustable desk. The "LifeBalance Station" by Rightangle (centre image of Fig. 1) is a semi-recumbent elliptical trainer. The cadence level influenced the exercise intensity. We did not use the original height adjustable desk, but a comparable height adjustable desk (Assenburg) as for the static conditions. The third dynamic workstation tested (right image of Fig. 1) was a common bicycle ergometer (Tunturi E60) combined with a height adjustable desk. The cadence level did not influence the exercise intensity. At the time of our study (May 2012), we could not find a commercially available bicycle workstation that suited the purpose of our experiments. The movement intensities used were: 2.5 km/h on the treadmill (WALK); level 12 at 40 revolutions per minute (17 Watt) on the semi-recumbent elliptical trainer (RET); 25% (CYC25) and 40% (CYC40) heart rate reserve (HRR) on the bicycle ergometer, corresponding to 56 (SD 21) and 85 (SD 28) Watt, respectively. The relationship between HRR and cycling intensity (in Watts) was individually determined with a submaximal Åstrand-test (Noonan and Dean, 2000). The movement intensities for WALK and RET were chosen to be comparable with CYC25, but were not individually determined.

2.4. Tasks and assessments

The series of tasks selected for this study were aimed at simulating basic office tasks and included a typing task (5 min), a reading (and correcting) task (5 min), a telephone task (3 min) and a task examining mouse dexterity (5 min). In addition, a selection of four tests from a website (http://cognitivefun.net) were used (6–8 min in total) to assess attention ("Go/No-go task"; Nosek and Banaji, 2001), perceptual performance ("Fast Counting task"; Simon et al., 1993), executive memory performance ("Eriksen flanker test"; Eriksen and Eriksen, 1974) and working memory performance ("N-back" with $N = 2$; Kirchner, 1958). The parameters assessed were speed and accuracy measured by the computer (Table 3), and speed and accuracy perceived by the participant (7-point Likert scale). For the typing task, the participants were required to copy a text from a window in the top half of the computer screen to a Word document situated in the bottom half of the screen (as in Straker et al., 2009). Each mistyped word or punctuation was counted as one error. For reading, participants were asked to read a text from the screen. These texts had one character rotation (e.g., "hlelo" instead of "hello") after approximately every 100 words. The number of missed character rotations was assessed as accuracy. In the telephone task, participants were required to listen to a text spoken by the test leader and repeat it, one sentence at a time. Performance on the telephone task was not assessed objectively. The texts selected for the typing, reading and telephone tasks: had a comparable difficulty level; were used in a standard order during the day; and no text was repeated within the task set for one participant. The mouse dexterity test used was based on Fitts' Law (Fitts, 1954) and consisted of two different tests: Random Circles and Multi-direction (Hillcrest Freespace® MotionStudio Version 3.4.0). For the first test, "Random Circles", a total of 100 dots of different sizes appeared randomly on the screen. Dots had to be hit before the next circle would appear. In the second test, "Multi-direction", 100 dots were presented in four rings. The outer rings had smaller dots. The test started with clicking on dots of the inner ring, from one side of the ring to the other in clockwise direction. Hit and missed dots disappeared but missed dots were not replaced. In both mouse dexterity tests, participants were required to click on the dots as fast as possible.

Table 2
Outline of workstations and conditions.

Workstations	Type	Conditions
Sit-stand office desk	Static	SIT; STA
Treadmill Desk	Dynamic	WALK
Semi-recumbent elliptical trainer	Dynamic	RET
Bicycle ergometer	Dynamic	CYC25; CYC40

2.5. Instrumentation

Various measures of physical activity and physical workload were assessed in this study, but are not reported because the focus of this article is on work performance. Heart rate was captured with a Polar heart rate monitor (model RS400), while a 3D kinematics measurement system (MVN, Xsens Technologies, The Netherlands) recorded the position of markers on the lower arms, upper arms, scapula (shoulder blades), sternum (breast bone), lower spine, and head.

2.6. Procedure

The complete protocol, including preparatory activities, rest breaks and filling out questionnaires, took one full working day (7–8 h) for each participant. Participants were asked to refrain from high intensity physical activity the day before the test, as well as alcohol and recreational drugs. On the test day itself, they were asked to avoid caffeine-containing drinks and to wear flat shoes and comfortable clothes. The test leader arranged food and drinks for the day. In the morning, the air-conditioning was set at 18 °C (±1 °C). First, a general questionnaire was completed with items on demographics, physical activity (Douwes and Hildebrandt, 2000), job type, working hours, main tasks and expectations about the dynamic workstations. Next, the resting heart rate (HR) was measured in supine position, after at least 3 min, when the HR remained stable. Then, participants performed the Åstrand

Fig. 1. The dynamic workstations tested, from left to right: a treadmill (Lifespan), a semi-recumbent elliptical trainer (LifeBalance Station), and a bicycle ergometer (Tunturi E60), all combined with a height adjustable desk.

submaximal cycling test to determine their fitness (See Table 1: estimated VO_2 max based on the nomogram of Åstrand-Rhyming) and personalize intensities for cycle ergometer conditions, following the protocol described in Noonan and Dean (2000). Next, the Xsens system was applied to the participant's body, relevant body dimensions were measured and a calibration pose was captured by the system. Prior to the start of the data capturing phase, participants were instructed on the tasks and were able to practice all tasks once on the standard office workstation in a seated position. At the start of each condition, participants were familiarised with the dynamic workstation for a period of 3 min before starting with the tasks. Kinematic data and heart rate (HR) were recorded during all conditions and a questionnaire was filled out after each condition. The questionnaire contained items about perceived task performance (speed and accuracy); local perceived comfort, discomfort and fatigue; and usability of the workstation for office work. Of the questionnaire, only the perceived performance results are included in the present paper. A recovery time of 15–20 min was applied between conditions, including a 30–40 min lunch break after the 3rd condition. After the 6th and final condition, each participant answered 8 interview questions about the dynamic workstations (appreciation and motivation) and their current way of working (flexible or fixed place and hours). The results of this interview are also not included in the present paper.

Table 3
Objective measures for speed and accuracy of all five tasks. Variable names are displayed in italic.

Task and tests	Speed	Accuracy
Typing task	Number of characters typed per minute *(TYPE-spe)*	Number of mistyped words and punctuation *(TYPE-acc)*
Reading and correcting task	Number of characters read per minute *(READ-spe)*	Number of missed character rotations *(READ-acc)*
Mouse task		
Random Circles	Average reaction time *(RC-spe)*	Number of missed circles *(RC-acc)*
Multi Directional	Average reaction time *(MD-spe)*	–
Cognitive task		
Go/No-Go	Average reaction time *(GNG-spe)*	% correct responses *(GNG-acc)*
Fast Counting	Average reaction time *(FC-spe)*	% correct responses *(FC-acc)*
Eriksen Flanker	Average reaction time *(EF-spe)**	% correct responses *(EF-acc)**
N-Back	Average reaction time *(NB-spe)*	% correct responses *(NB-acc)*
Telephone task	–	–

*Average of congruent and incongruent scores.

2.7. Data processing and statistical analysis

We collected 23 performance parameters of which 16 described the objective task performance and 7 described the perceived task performance. Statistical analyses were performed with Statistical Product and Service Solutions (SPSS) version 20.0. Paired *T*-tests (one-tailed) were performed to test whether the objective and perceived task performance parameters were either lower (hypotheses 1 and 3) or higher (hypothesis 2) in the dynamic workstation conditions (RET, WALK, CYC25, CYC40) compared to the reference condition (SIT). A paired *T*-test (one-tailed) was used to test whether objective task performance was lower while working on the bicycle ergometer at the higher movement intensity (CYC40) compared to the lower intensity (CYC25, hypothesis 1). A paired *T*-test (two-tailed) was used to compare the standing workstation condition (STA) with the reference condition (SIT), for both the objective and perceived task performance (hypothesis 4, no difference assumed). Significance was accepted at $p < 0.05$.

3. Results

3.1. Objective task performance

Performance of the mouse dexterity task was significantly affected by all dynamic workstation conditions compared to the SIT condition (Table 4 and Fig. 2). For both mouse tests, speed measures (*RC-spe* and *MD-spe*) deteriorated and more errors (*RC-acc*) were made during the dynamic workstation conditions. For the static workstation condition STA, a significant deterioration was only found for mouse speed measure *RC-spe* compared to SIT condition. The performance on the typing task was only affected by WALK condition (Fig. 3). The typing speed in WALK condition was significantly lower than during the SIT condition. The task performance for reading was not affected by the dynamic workstation or standing conditions (Fig. 4). Furthermore, the performance of the cognitive tasks was not affected by the dynamic or standing conditions, except for the accuracy on the N-Back test. In condition CYC40, accuracy on the N-Back test decreased compared to SIT condition. There was no significant difference between the two bicycling intensities (CYC25-CYC40) in affecting the objective task performance in any of the four tasks (Figs. 2–4).

3.2. Perceived task performance

All perceived performance measures were affected by all dynamic workstation conditions but not by the standing condition

Table 4
T-tests results ($N = 15$; $p \leq 0.05$), comparing objective task performance of all workstation conditions (STA; WALK; RET; CYC25; CYC40) with the reference condition (SIT); and comparing movement intensities on the bicycle ergometer workstation (CYC25-CYC40). These statistic results refer to Figs. 2–4. Significant differences marked bold ($p < 0.05$) or italic ($p < 0.10$).

p-values		Static	Dynamic				
		STA	WALK	RET	CYC25	CYC40	CYC25-CYC40
		2-tailed	1-tailed	1-tailed	1-tailed	1-tailed	1-tailed
Mouse task	RC-spe	**0.030**	**0.000**	**0.004**	**0.027**	**0.025**	0.316
	RC-acc	0.617	**0.001**	**0.029**	**0.038**	**0.003**	0.102
	MD-spe	0.713	**0.000**	**0.029**	**0.019**	**0.024**	0.461
Typing task	TYP-spe	0.265	**0.000**	0.212	0.124	0.161	0.255
	TYP-acc	0.791	*0.062*	0.130	*0.077*	0.119	0.313
Reading task	READ-spe	0.800	0.191	0.390	0.449	0.221	0.165
	READ-acc	0.896	0.440	0.422	0.167	0.388	0.175
Cognitive task	FC-spe	0.668	0.312	*0.052*	*0.064*	*0.091*	0.331
	FC-acc	0.746	0.484	0.282	0.418	0.347	0.256
	GNG-spe	0.947	0.455	0.392	0.304	0.377	0.402
	GNG-acc	0.133	0.358	0.408	0.438	0.170	0.206
	EF-spe	0.705	*0.070*	0.220	0.260	*0.065*	0.184
	EF-acc	*0.059*	0.332	*0.056*	0.346	0.485	0.343
	NB-spe	0.702	0.376	0.144	0.290	0.149	0.378
	NB-acc	0.410	0.199	*0.052*	0.189	**0.008**	*0.067*

(Table 5 and Figs. 5 and 6). Both perceived speed and accuracy of the mouse, typing and reading task were rated significantly lower compared to SIT condition. Participants also rated the quality of the telephone conversation significantly lower during all dynamic workstation conditions compared to SIT condition. The perceived quality of the telephone conversation at the STA condition did not differ from the SIT condition.

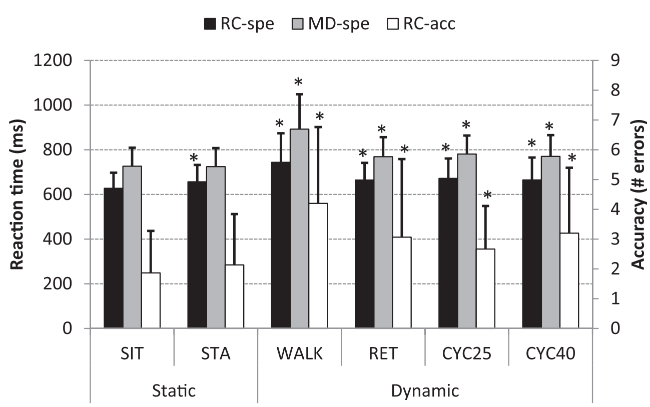

Fig. 2. Speed and accuracy measures of the mouse pointing and clicking task while working in 6 workstation conditions. A higher reaction time implies lower speed and a higher number of errors implies a lower accuracy. The asterisk (*) marks a significant difference ($p < 0.05$) with the reference condition (SIT) as indicated by t-testing.

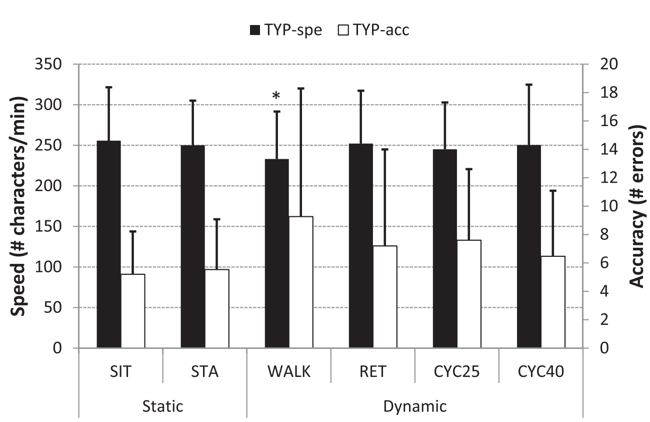

Fig. 3. Speed and accuracy measures of the typing task while working in 6 workstation conditions. A higher number of errors implies a lower accuracy. The asterisk (*) marks a significant difference ($p < 0.05$) with the reference condition (SIT) as indicated by t-testing.

4. Discussion and conclusion

The present study evaluated objective and perceived work performance of four standardized common office tasks and one set

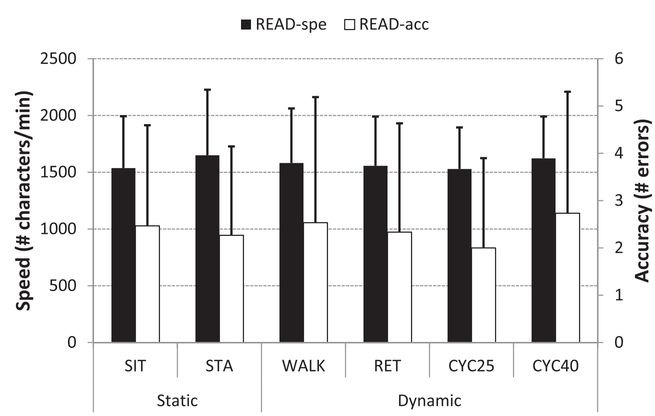

Fig. 4. Speed and accuracy measures of the reading and correcting task while working in 6 workstation conditions. A higher number of errors implies a lower accuracy. The asterisk (*) marks a significant difference ($p < 0.05$) with the reference condition (SIT) as indicated by t-testing.

Table 5
T-tests results ($N = 15$; $p \leq 0.05$), comparing perceived task performance of all workstation conditions (STA; WALK; RET; CYC25; CYC40) with the reference condition (SIT). These statistic results refer to Figs. 5 and 6. Significant differences marked bold ($p < 0.05$).

p-values		Static	Dynamic			
		STA	WALK	RET	CYC25	CYC40
		2-tailed	1-tailed	1-tailed	1-tailed	1-tailed
Mouse task	Speed	0.150	**0.000**	**0.000**	**0.001**	**0.001**
	Accuracy	0.152	**0.000**	**0.000**	**0.005**	**0.002**
Typing task	Speed	**0.029**	**0.000**	**0.003**	**0.001**	**0.000**
	Accuracy	0.305	**0.000**	**0.009**	**0.006**	**0.003**
Reading task	Speed	0.150	**0.002**	**0.004**	**0.045**	**0.020**
	Accuracy	0.212	**0.001**	**0.001**	**0.041**	**0.019**
Telephone task		0.249	**0.003**	**0.000**	**0.000**	**0.000**

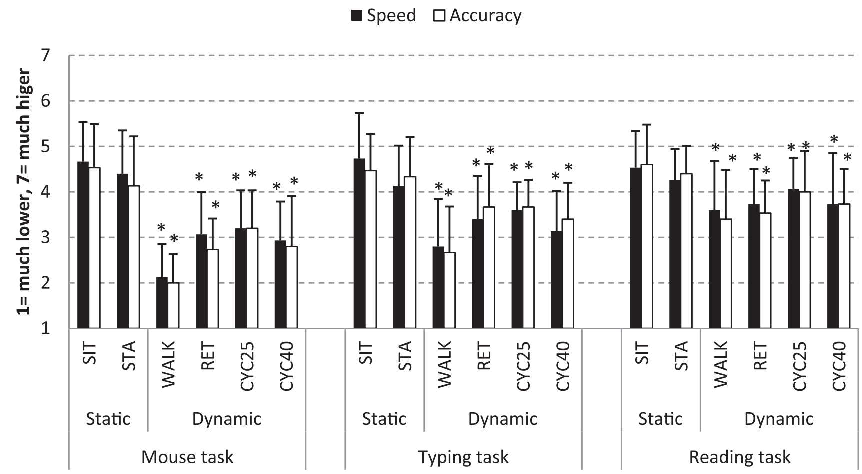

Fig. 5. Perceived speed and accuracy of a mouse pointing and clicking, a typing, and a reading and correcting task while working in 6 workstation conditions. Perceived performance "compared to my normal workstation" is rated on a 7-point Likert scale (1 = much lower, 4 = equal, 7 = much higher). The asterisk (*) marks a significant difference ($p < 0.05$) with the reference condition (SIT) as indicated by t-testing.

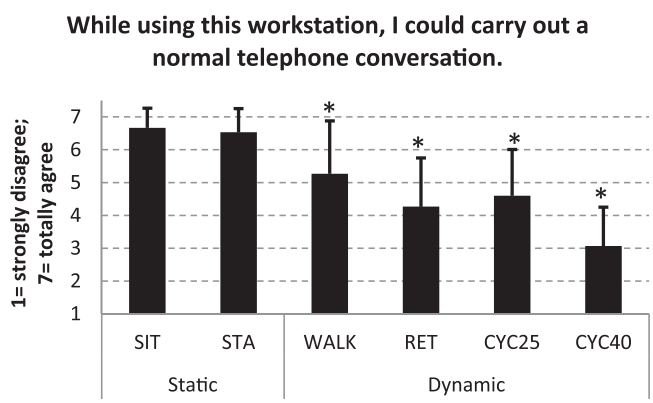

Fig. 6. Perceived quality of a telephone conversation while working in 6 workstation conditions. Perceived performance is rated on a 7-point Likert scale (1 = strongly disagree, 4 = neutral, 7 = totally agree). The asterisk (*) marks a significant difference ($p < 0.05$) with the reference condition (SIT) as indicated by *t*-testing.

of cognitive function tests while participants used three different dynamic workstations and one standing workstation compared to a standard sitting position.

4.1. *Effects on objective work performance*

4.1.1. *Typing and mouse tasks*

As hypothesized, movement of the upper body when working on a dynamic workstation affects short term work performance compared to a standard seated workstation. The measured performance of a mouse dexterity task deteriorated while using the treadmill, bicycle ergometer and semi-recumbent elliptical trainer. The measured speed of a typing task also deteriorated while walking on the treadmill. However, in contrast to our hypothesis, typing speed did not deteriorate on both the bicycle ergometer and the semi-recumbent elliptical trainer. The upper body is more stable during these seated dynamic workstations (i.e., the bicycle ergometer and elliptical trainer) compared to a treadmill workstation (Botter et al., submitted for publication). Therefore, tasks requiring fine motor actions were less affected by seated dynamic workstations than hypothesised. Typing and mouse task performance were evaluated in several studies using a comparable treadmill workstation (Straker et al., 2009; John et al., 2009; Ohlinger et al., 2011; Thompson and Levine, 2011; Funk et al., 2012), one study using a bicycle workstation (Straker et al., 2009) and one study using a 'recumbent exercise cycle' (Elmer and Martin, 2014). In the studies using a treadmill, the walking speed was set between 1.3 and 3.2 km/h. In general, the results of these studies show a modest deterioration in mouse pointing speed (6%–14%) and a substantial increase in mouse pointing errors (106%). For typing tasks, a modest deterioration in typing speed (2%–16%), with no or a minor increase in typing errors (0%, 3%) were found. Comparable results were found in our study. At a walking speed of 2.5 km/h, mouse pointing speed deteriorated with 23% and mouse pointing error increased with 121%. For the typing task a 9% deterioration in typing speed with no significant decline in typing errors was found.

The effects of cycling on short term work performance was evaluated in one study (Straker et al., 2009), with a cycling intensity of 5 W and 30 W. The objective work performance showed minimal to no deterioration for typing, whereas a clear deterioration in mouse performance was seen (5% decrease in speed, 61% increase in errors). However, the deterioration in mouse performance was smaller then while using a treadmill workstation. In our study, comparable effects were found, but for considerably higher cycling intensities (25% HRR: 56 ± 21 W and 40% HRR: 85 ± 28 W): the two cycling intensities had no effect on typing performance. Both mouse dexterity tests showed 6–8% decrease in speed (both intensities), and an increase in errors of 42% (at 25% HRR) and 68% (at 40% HRR). The measured performance of the mouse and typing task did not deteriorate for a higher cycling intensity. As in our study, Elmer and Martin (2014) found no deterioration in typing speed and errors using a recumbent exercise cycle at a light intensity.

Although the task set-up and walking or cycling intensities differed between studies, all studies conclude that mouse handling accuracy (in short duration tasks) is strongly affected while using a dynamic workstation. Mouse pointing speed and typing speed are affected, but to a lesser extent. Treadmill workstations seem to affect short term work performance more than bicycle workstations and elliptical trainers, probably because the upper body is less stable during walking compared to seated dynamic workstations (Winter, 1995).

4.1.2. *Reading and cognitive task*

The hypothesized improvement of short term task performance, due to positive effects of moderate levels of aerobic exercise on mental processes (Tomporowski, 2003), was not found in this study. The measured performance of a reading task and of almost all cognitive function tests did not significantly improve, nor worsen, while moving on either of the three dynamic workstations. For one of the cognitive function tests the measured accuracy declined, but only at the higher cycling intensity (40% HRR) compared to sitting. The physical intensity of 3 of the 4 conditions may not have been sufficient (<40% HRR[1]) to improve information processing. After all, we know from the Tomporowski review (2003) that the intensity of aerobic activity is relevant for the relation between physical activity and mental processes. Many studies show an inverted U-shape between intensity of exercise (or physiologic parameter) and the speed of response or speed of decision making, the latter being lower both in rest and during higher exercise intensities and peaking around 40% of maximum oxygen uptake or 45% HRR. However, the higher cycling intensity condition in our study was at 40–45% HRR, yet also did not show an improvement of task performance. A second option for the lack of association with mental processes may be the short task duration (3–8 min). For our results, i.e. no effects, are in agreement with those of previous studies that assessed the effect of physical activity on reading comprehension (John et al., 2009), selective attention, cognitive flexibility and processing speed and memory (Ohlinger et al., 2011). These studies used tasks with similar durations as we did. Thus, the positive effects of moderate levels of aerobic exercise on mental processes as indicated by Tomporowski (2003) have not yet been observed while using dynamic office workstations.

4.2. Effects on perceived work performance

As expected, participants perceived their short term task performance to deteriorate on all dynamic workstations and in all tasks, although this is in contradiction with the objective performance measures. Participants were not accustomed to working on dynamic workstations and may therefore have considered the movements to be a distraction, resulting in a lower perceived performance. Straker et al. (2009) also found decreases in perceived work performance while using a treadmill and bicycle workstation. In his study, participants perceived an overall decrease in speed (13%–26%) and increases in error rate (13%–28%), on a 5-point Likert scale, while performing a typing and a mouse task. Similarly, we found reductions in perceived speed of 12% (reading) to 54% (mouse dexterity) and decreases in perceived accuracy of 13% (reading) to 56% (mouse dexterity) across the four dynamic workstation conditions, using a 7-point Likert scale. Accordingly, both studies report that participants perceive their task performance to decline considerably when combining computer tasks with physical activity. In contrast to the findings of Straker et al. (2009) and our study, other studies do not describe a decline in perceived performance while using a dynamic workstation (Thompson et al., 2008; Thompson and Levine, 2011; Carr et al., 2011). These studies were field studies, which did not use standardized office tasks. In a laboratory set-up, such as in Straker et al. (2009) and our study, participants may be more focused on their productivity, making them more sensitive to small changes.

4.3. Effects on work performance of a standing workstation

As hypothesized, most of the short term objective and perceived performance parameters were not significantly different when working in a standing position compared to a sitting position. An exception was a decline in speed of the mouse dexterity task at the standing workstation. Although standing without moving is a relatively stable position, small upper body movement may still interfere with the high precision demands of a mouse pointing task. Although several studies evaluated the effects of standing workstations on posture and comfort (e.g., Laestadius et al., 2009; Hasegawa et al., 2001), none of them evaluated the effect of a standing workstation on work performance of the office tasks studied here.

4.4. The relevance to office workers and employers

This study shows that office workers are able to work on a dynamic workstation with equal performance on the basic office tasks, high precision mouse tasks excluded.

All dynamic workstations in this study can contribute to interrupting static sitting and reducing the adverse health effects of sedentary behaviour. However, prospective studies are needed to establish which of the adverse health effects can be tackled by dynamic workstations and to what extent.

Already in 1981, Cox et al. showed that participation of employees in exercise classes could lead to small (3–4%) gains in productivity and a reduction in absenteeism of 22%. Van Dongen et al. (2011) reviewed the financial return of worksite health promotion programs aimed at increasing physical activity, concluding that these programs generate financial savings in terms of reduced absenteeism costs, medical costs or both. The same might apply to the introduction of dynamic workstations in the office, thus benefiting both office workers and employers.

Additionally, the use of dynamic workstations can help office workers to alternate postures, which seems to be a significant health factor in individual ergonomics. For example, Hasegawa et al. (2001) found that alternation between sitting and standing working posture had a positive effect on productivity, tiredness and restlessness for participants working with a light repetitive task. The postural and physiological effects of dynamic workstations compared to conventional sitting and standing workstations are not part of this study though, but described in a different paper (Botter et al., submitted for publication).

Concluding, from a work performance perspective the introduction of dynamic workstations in offices seems a promising solution to reduce the health risks of sedentary work. However, the perception of decreased performance may complicate the acceptance of dynamic workstations.

Acceptability and integration of these workstations with daily work requires attention. On the one hand, feasibility studies do report positive opinions of users; after 4 weeks of using a treadmill, 25 employees at a hospital express that "I would use it if this were an option" (Thompson et al., 2008). Also, 18 employees working in a sedentary occupation say that the portable pedal exercise machine they were given access to during 4 weeks was "easy to use" and "if offered to me by my employer, I would use the machine while at work" (Carr et al., 2011). On the other hand, the actual use (compliance) of the pedal machine was shown to progressively decline over the course of 4 weeks, from 100% on day 1 to ca. 50% on working day 13 to just below 20% on working day 20 (Carr et al., 2011). Even with additional motivational elements like a website and e-mail reminders, the actual use of the pedal machine (days pedalled/days with access) was only 38% (Carr et al., 2013).

4.5. Strengths and limitations of this study

The strengths of this study are that the experiments have been performed in an office-like laboratory environment without

[1] The average HRR (%) of the conditions were: 10 (SIT), 14 (STA), 22 (WALK), 29 (RET), 32 (CYC25), 43 (CYC40). Data published in the Master thesis of M. Zwetsloot (2013).

disturbances, that standardised tasks and a randomised protocol for conditions and tasks were used. All participants have performed all tasks on all dynamic workstations, making within-subjects comparisons possible.

On the other hand, these strengths also incorporate some limitations. First, the standardised task measures used for estimating computer use performance and cognitive function may not have been adequate representations of every day office work performance. The task durations (3–8 min) are much shorter than in real life, thereby limiting the transferability to computer tasks in offices. The short task durations are comparable, though, to those used in previous studies: 5 min to assess speech quality while walking (Cox et al., 2011), a 4 min typing test while walking (Funk et al., 2012), 3 min typing and 4x20 mouse clicks and 2 min of combined keyboard and mouse use while walking or cycling (Straker et al., 2009). Also, the cognitive task may not have been complex enough to simulate a realistic work task, and the mouse task was too specialized, i.e. there are hardly any office tasks that fully require mouse operation. For the reading and correcting task some mouse use was necessary as well, which may have been more representative for every day computer use. The tasks had a rather short (3–5 min) duration, pushing participants to their maximum performance. Perhaps at a lower performance level, more representative for a whole working day, dynamic workstations will have a positive effect, directly or after the exercise. For future studies we invite researchers to focus on the incorporation of dynamic workstations into participants' daily work routines and measure the effects on their objective and perceived work performance.

Another point of concern is the sample of participants. These were relatively young (mean age 29), lean (mean BMI 22.3) and fit (on average 2 h moderate and 1 h intensive physical activity per week). Generalizing our results to the general office population might, thus, be limited for the perceived performance data, as these may be affected by age or fitness level. As to the objective performance data, we assume that the short duration of tasks has a much greater impact on generalizability than the sample of participants.

4.6. Conclusions

Insufficient physical activity has adverse health effects and sedentary work has proven to be an independent risk factor. Both standing and dynamic (or active) workstations offer the possibility to increase physical activity and reduce sedentary time at the workplace during daily office work. Performance of most standard office tasks (reading and correcting, re-typing a presented text and cognitive tasks) was hardly affected while using a standing or a dynamic workstation. However, a computer task that requires fine motor actions of the hands (mouse pointing and clicking) was affected by the movements at a dynamic workstation. This was also the case at the standing workstation. Despite generally an equal objective performance on dynamic workstations, participants perceived that their performance deteriorated. These objective and perceived performance results correspond with findings from other studies. More field studies are necessary to determine work performance and acceptance of dynamic workstations in a real office environment.

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